LOW TEMPERATURE CARBONIZATION OF COAL,

A SOLUTION TO THE SMOKE NUISANCE PROBLEM

AND A METHOD OF MORE FULLY UTILIZING THE COAL

RESOURCES OF THE ROCKY MOUNTAIN REGION.

By

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A thesis submitted to the Faculty of the University of Utah in partial fulfillment of the requirements for the degree of Bachelor of Science.

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Approved by ______________________

"GIVE INSTRUCTION TO A WISE MAN,

AND HE WILL BE YET WISER;

TEACH A JUST MAN,

AND HE WILL INCREASE IN LEARNING."

--Proverbs.

FOREWORD

Abatement of the smoke nuisance in Salt Lake City, and all other communities as well, is unquestionably an economic and social problem of major importance. Smoke represents a vast economic loss and also a definite danger to the health and comfort of all individuals concerned.

Since the problem is so far reaching and is of interest to people from all walks of life, any thesis which discusses a solution should not be purely technical but of such a nature that it can be appreciated by anyone who reads it. It is the object of the authors to present their findings in this manner.

The subject matter discussed on the pages to follow is a continuation of very extensive research studies on low-temperature carbonization of Rocky Mountain coals. These studies have been made by the United States Government, the State of Utah, and the School of Mines and Engineering of the University of Utah. These studies present a very satisfactory method of eliminating the smoke nuisances, and of more fully utilizing the coal resources of this locality.

ACKNOWLEDGMENT

The authors of this thesis desire to acknowledge the support of Professor E. H. Beckstrand, Head of the Mechanical Engineering Department at the University of Utah. His foresight, encouragement, and able assistance have been deciding factors to the success of the investigations described in this report.

The authors wish to express their sincere appreciation to Mr. L. C. Karrick, Fuels Engineer, and formerly Refining Engineer, for the United States Bureau of Mines. Mr. Karrick directed the research; the methods and processes used were largely those worked out by him, and his excellent cooperation and advice, as well as material assistance, were most valuable.

We are deeply indebted to Messrs. Clark Jacobsen and George W. Carter, graduates in Mechanical Engineering from the University of Utah, for their assistance in designing, constructing, and operating the coal processing plant.

Dean R. B. Ketchum, of the School of Mines and Engineering, at the University of Utah, has supported the investigations unresignedly. We greatly appreciate the support and help he has given.

To Mr. C. E. Ohrn, Mechanic for the Engineering Experiment Station, we offer appreciation for his assistance in the construction of the plant, also to Mr. Emil Huber, eningeer in charge of the heating plant, for his assistance.

In order that data could be taken, fuel had to be secured. We thank The Citizen's Coal Company, The Western Fuel Company, and also Mr. Reese of Coalville for their interest and the coal they have donated.

We wish to thank Mrs. Alice Merrill Horne, Executive Secretary, of the Smokeless Fuel Federation of Utah, for her and their cooperative work in helping us with this research by the donation of a new Oakland Foundry Company kitchen range for testing purposes.

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INTRODUCTION

Increase of the smoke nuisance in the United States has followed the trend of industrial development. When cities were but small towns and a larger portion of the population lived in the outskirts, the problem of smoke control was unknown. As industry began to grow and people began to concentrate in cities, a tremendous increase in heat and power utilization followed, in which coal played a major part. At this time, five-sixths of the coal used was bituminous.

Bituminous coal contains a high percentage of volatile matter. The liberation of and failure to completely burn these volatiles results in the formation of a soot and tar-laden black smoke. On escaping into the atmosphere, the smoke causes injuries to homes, buildings, merchandise, and to the foliage of our cities, which, in turn, occasions losses and necessitates extra cleaning and repairs. The health of the community is also seriously imparied by breathing the smoke-laden air.

One should not be mislead into believing that the light yellow or brown smoke that frequently appears from the chimneys of stoker-fired residence and office building heating plants is an improvement over the more common black smoke. It has been shown that this yellowish smoke is composed largely of oil or tar vapors which are distilled from the coal and have undergone practically no combustion. These vapors settle on wall paper, household effects and clothing, and cannot be removed excepting with difficulty and only with the use of dry-cleaners solvent.

Property damage and the serious public health hazard alone justify community investigation of more scientific methods of using coal. In addition, it has been shown by the researches of Mr. L. C. Karrick and others (1.), and will be further shown by this thesis, that rich

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(1.) The analyses of the low-temperature carbonization products obtained from Utah Coals by L. C. Karrick, Refinery Engineer U.S. Bureau of Mines, Pittsburgh, Pennsylvania, 1924-1926: -

"Composition of Light Oils From Low-Temperature Carbonization of Utah Coals", by R. L. Brown, R. B. Cooper, 1926.

"Composition of Tar From Low-Temperature Carbonization of Utah Coal. -- I", by R. L. Brown, B. F. Brenting, 1928.

"Composition of Tar From Low-Temperature Carbonization of Utah Coal. -- II", by R. L. Brown, R. N. Pollock, 1929.

"Study of Wax From Low-Temperature Tar", by J. D. Davis, K.M. Irey, 1934.

"Fractional Analysis of Gas From the Low-Temperature Carbonization of Utah Coal", by Frey and Yant, Ind. Eng. Chem. 19, 21 (1927).

"Shale Oil", by McKee, Karrick and others, American Chemical Society Monograph, No. 25.

"Cracking of Low-Temperature Utah Coal Tar", by C. R. Kinney,, T. M. Burton, L. C. Karrick, Salt Lake Mining Review, Vol. 35, No. 7, Page 5, 1933.

"Design of Coal Treating Plant Using Karrick Process", by Clifford N. Stutz and W. A. Larsen, B.S. Thesis in Civil Engineering, University of Utah, 1932. 2

"Oil Reserves in The Oil Shales and Coal Deposits of Utah, and The Economic Factors Affecting their Utilization", by D. Clarence Schmutz, Masters Thesis in Economics, University of Utah, 1932. /

"Engineering Factors Relating to the Utilization of the Cannel Coals of Southern Utah", by S. C. Jacobsen, G. W. Carter, Bachelor Thesis in Mechanical Engineering, University of Utah, 1933. 2

"Engineering Factors Relating to the Production of Smokeless Fuel, Oil and Gas From Rocky Mountain Coals by Low-Temperature Carbonization", by G. W. Carter, Master's Thesis in Mechanical Engineering, University of Utah, 1934. 2

oils and gases which would otherwise be dissipated in the form of smoke, can be recovered from the Utah coals.

The damage occasioned is well put forth in the following quotation from the United States Bureau of Mines Bulletin No. 254(2):

"The Chicago Association of Commerce, through its committee of investigation on smoke abatement, has thoroughly investigated the damage from atmospheric pollution. The conclusions of the committee are as follows:

HEALTH

"1. There is a general agreement among sanitary authorities that polluted air is harmful to health.

"2. At the present time, there is no accurate method of measuring this harm nor of determining the relative responsibility of the different elements that enter into the mixture of gases and solids commonly referred to as atmospheric air.

"3. The direct effect of smoke or any of its attributes, including soot, dust, and gases, in amounts which may ordinarily pervade the atmosphere of a smoky city is not shown to be detrimental to persons in normal health.

"4. The direct effect of smoke upon those who are ill has been most extensively studied in connection with tuberculosis and pneumonia.

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(2) "Smoke Abatement Investigations at Salt Lake City, Utah, U.S. Bureau of Mines Bulletin, No. 254.

It appears that smoke does not in any way stimulate the onset of tubercular processes, nor militate against the rapidity of recovery when once this disease has been contracted, but that it has a direct antiseptic effect and tends to localize the disorder. In cases of pneumonia, the effect becomes seriously detrimental.

"5. In addition to these direct effects, indirect effects result from the diminution of sunlight and the increase in fogs, clouds, and haze.

"6. The general physical tone is lowered as the result of long-continued breathing of polluted air.

VEGETATION

"1. That smoke may exert injuries effects on vegetation. These effects may be direct or indirect. The direct effects are slow in asserting themselves. Trees and plants exposed to them gradually lose vigor through a series of years until they perish.

"2. That the products of combustion which are most pronounced in their direct effects are the soot and tar discharges and the sulphurous gases, though injury may occur as a result of increased acidity in the soil caused by smoke.

"3. That the indirect effects appear as a result of fogs induced by smoke, the occurence of which has sometimes injured or destroyed tender plants.

"4. That no basis is supplied upon which to judge the amount of smoke which is necessary to bring about injurious results; the effects described are generally such as have attended exposure to severe conditions.

PROPERTY

"1. Many of the facts involved are variable and indeterminate.

"2. Concerning the sources of loss and damage occasioned by smoke the following is to be noted: (a) The loss and damage caused by the gaseous products of combustion are due chiefly to their sulphur content. (b) The extent of loss and damage arising from the solids in smoke will, other things being equal, depend upon the character of the solids. For example, solids in the form of soot and oily distillates of fuel oil deface more quickly than solids in the form of coke or ash particles. The former are characteristic of smoke from low-temperature fires, such as those of domestic service; the latter are characteristic of smoke from high-temperature fires, such as those of high-pressure steam boilers and steam locomotives."

Additional light may be thrown on the subject of property damage in Salt Lake City by the statements of Mr. Blair Richardson, President of the Salt Lake Reality Association, in the Salt Lake Tribune of March 31, 1935. In this article, Mr. Richardson voices the opinion of the real estate dealers of the city on the very damaging effect of smoke on property. In addition to the loss suffered by the real estate owners, the architectural scope is very definitely limited. It seems to be of little value to apply advanced ideas on the appearance of buildings, because they all look very much the same after a few years exposure to the smoky atmosphere of the city. He further states that the actual damage from smoke to the homes and property of Salt Lake City is so great that people could really save money by paying twice the amount they now pay for coal for a suitable solid smokeless fuel. He feels further that the widespread knowledge of Salt Lake's bad smoke problem is certain to prevent a splendid growth and enrichment that the city could normally expect.

Extensive studies of the smoke problem have been made abroad. Quotations from a very informative British publication[3.] will add to and further illustrate the points stressed on the preceeding pages:

SMOKE AND HEALTH

By
John S. Taylor, M.D., D.P.H.
Assistant Medical Officer of Health, Manchester.

Respiratory Effects:

"It seems strange that of the three necessities of life, viz., food, water and air, legislation for air should have been so long delayed in spite of man consuming seven times as much of it by weight as he does food and water. We inhale about 35 pounds of air daily, and as a result, dwellers in industrial cities have lungs more or less similar to those of a coal miner, blackened, both on the surfaces and in the depths, due to the deposit of carbon.

(3.) "The Smoke Abatement Handbook", Published by The National Smoke Abatement Society, 23 King Street, Manchester.

PSYCHOLOGICAL EFFECTS

"The psychological effects of gloom require consideration. There is nothing more profoundly ingrained in our psychology than the beauty of light and the hateful ugliness of gloom. This psychology of light is an important factor, and its actual material results have been demonstrated by the Industrial Fatigue Research Board in that the output of work was found to be definitely diminished when lighting conditions were bad.

EFFECTS OF SMOKE UPON BUILDINGS

"The damage to buildings is one of the most obvious effects of the fall of smoke deposit. The tarry nature of the deposit enables it to adhere to whatever surface it may fall upon. The blackening of stones and brickwork, painted surfaces, and even interior paintwork and decoration is the initial effect, resulting in a considerable aesthtic loss and necessitating much expenditure if the original appearance is to be maintained. The sulphuric acids in the deposit, or brought down by the rainwater tend to react with the stone, which is composed generally of limestone with the formation of calcium sulphate. An increase in volume, or swelling takes place, so that the stone bursts, and the surface flakes off. Samples taken one-inch from the surface of the stone have been found to contain up to 33% calcium sulphate, which has also been found to a depth of nearly one-half inch. The drift of smoke may extend for considerable distances into the country, so that erosion of stone is found to be very marked in many buildings far from the cities.

"Serious corrosion takes place in metal structures of all kinds, which requires frequent attention and re-painting to preserve them. Steel rails in a town have been found to lose over one-pound weight per year as compared with a loss of only 0.18 pound on the seacoast.

"Sir Frank Baines have estimated that the cost due to smoke damage to government buildings is not less than $120,000 per year.

SMOKE AND VEGETATION

"Smoke acts upon vegetation in various ways, including: --

1. By the reduction in sunlight.

2. By the accumulation of solid deposit on the foliage of the plants, which closes the breathing pores of the leaves.

3. By acids lodging upon the leaves and growing points of of plants, which as a consequence are burnt and killed.

4. By the surface of the soil being covered over with a deposit of soot to such an extent as to hinder free passage of air to the roots.

5. Soil untilled for some time accumulates acids from the deposit and becomes "sour", and the lime content may be noticeably reduced in quantity, giving crops which in their turn are also lime deficient.

"The combined effects of these actions is very disastrous, as was shown by the well-known experiments carried out at Leeds University. The rate of growth of different types of vegetation was shown to diminish proportionately with an increase in the degree of atmospheric pollution in the area in which they were placed.

"From a purely economic viewpoint the loss is serious, especially in the cultivation of land in the industrial areas and in the upkeep of city parks and gardens....."

Coal is a basic commodity that enters into nearly every phase of industrial and social progress. Therefore, the factors that vitally effect the production and uses of coal should be scientifically regulated. Many times in past years slack coal has been sold at the Carbon County, Utah, coal mines for as low as fifteen cents per ton; often it has been given away in order to save car demurrage. Others of the small sized coals, depending upon their content of impurities, have experienced the same large price sacrifice in order to find a market. That anything so valuable to posterity as coal should in our advanced age be given away or sold at less than its cost of production, is a social and economic injustice which requires study and correction. The authors of this thesis believe that an engineering study of the economic facts, together with beneficiation and standardization of products, supported by public education on matters of proper usage, should reestablish the coal industry permanently on a sound footing.

A consumer does not generally accept the idea of using small sizes of coal, because of the excessive amount of impurities generally present, also, mostly because of the fact that the small size coal burns up more rapidly than large lumps under the customary unscientific firing methods.

Also, many will not even burn mine-run coal on account of the dirty slack it contains. In an effort to assign causes for the depressed bituminous coal market, many explanations have been given, such as the business depression, the encroachment of natural gas, and because of the more efficient methods under which coal and other fuels are being burned, all of which tend to curtail expansion of the coal industry. However, it is certain that the most vigorous force for stability that can be applied to the coal industry will be the standardization of the raw coal products, and the treatment of coals to convert them into solid and gaseous smokeless fuels, also oil products. It is known that nature controls in a great measure the cost of mining coal, due to the way it occurs and the care required in its extraction from the earth, and by virtue of such control becomes the most efficient economic leveler of mine costs throughout the country. It is also a fact that in mine operation, the prices secured for the small sizes of coal often spell the difference between profit and loss. It can easily be ascertained that the coal mines which are in operation during periods of market depression are the ones that were able to provide efficient cleaning and preparing equipment.

From a careful study of the literature on the developments in science and technology of coal processing, also from the early history of coal and its uses in the manufacture of crude oil, tar, coke, gas and many chemicals, it is quite obvious to the authors that a great coal-products industry based on low-temperature carbonization is much delayed in coming in the United States. Surely science and engineering have not been awake to the opportunity offered by coal, one of the nation's most valued resources, to solve the smoke of our cities, to develop a source of crude oil that will supply the "Base load" of our country's oil and gas requirements, and, to provide a very large new industry in which labor will be permanently employed. Foreign countries have these industries well under way!

Prior to 1860, there were fifty-five companies in the United States manufacturing crude oil from coal and some were refining several hundred barrels per day of the oil. This industry went out of existence when Pennsylvania crude petroleum was discovered in the vicinity of the coal-treating plants. The few oil products, namely, kerosene, lubricating oils, and wax for candles, did not provide sufficient profit for the coal oil manufacturers to continue to operate. There was little demand for the rich coal gas, and no urgent need for a solid smokeless fuel.

Today, however, the technical and economic picture has changed; The entire country has become "gas wise", and there is a growing demand for gaseous fuels, with "regulated heating" of homes; this can all be accomplished from coal. There is a tremendous and growing market for gasoline and diesel fuels for internal combustion engines; these liquid fuels when made from coals are superior to the best petroleum gasolines. The smoke of our cities which is responsible for billions of dollars loss each year in our cities, also the cause of much of the bronchial and other sicknesses and deaths of our cities, cannot be eleminated economically without the development of a new fuel which will burn as easily as coal in all present coal-burning equipment; this new fuel, with all its desired properties, can be made from Utah bituminous coal, as proved in this investigation. It has been said by some of the foremost authorities of the day, that it is both unscientific and an economic crime to burn raw coal!

Progressive people of Salt Lake City have renewed their interest in smoke abatement and are beginning to show a determination to seriously take up the matter and adopt a solution. Efforts in the past have been many, but without sufficient city and state backing, have been lost. The need of smoke abatement has become so vital that it is at present one of the most important civic questions.

If smoke abatement were merely an engineering problem, it would be a comparatively simple one, considering the vast amount of science and engineering information that is available to the public, but experience in the past has shown that it is also a psychological problem. The attitude of the public appears to be a larger barrier to surmount than the solution of the technical questions involved. Thus, the part played by the civic organizations and other bodies is of great importance. Until the public is thoroughly aroused and appreciates the value of the scientific investigations now completed, and demands smoke abatement, no elimination of our cities smoke can be expected.

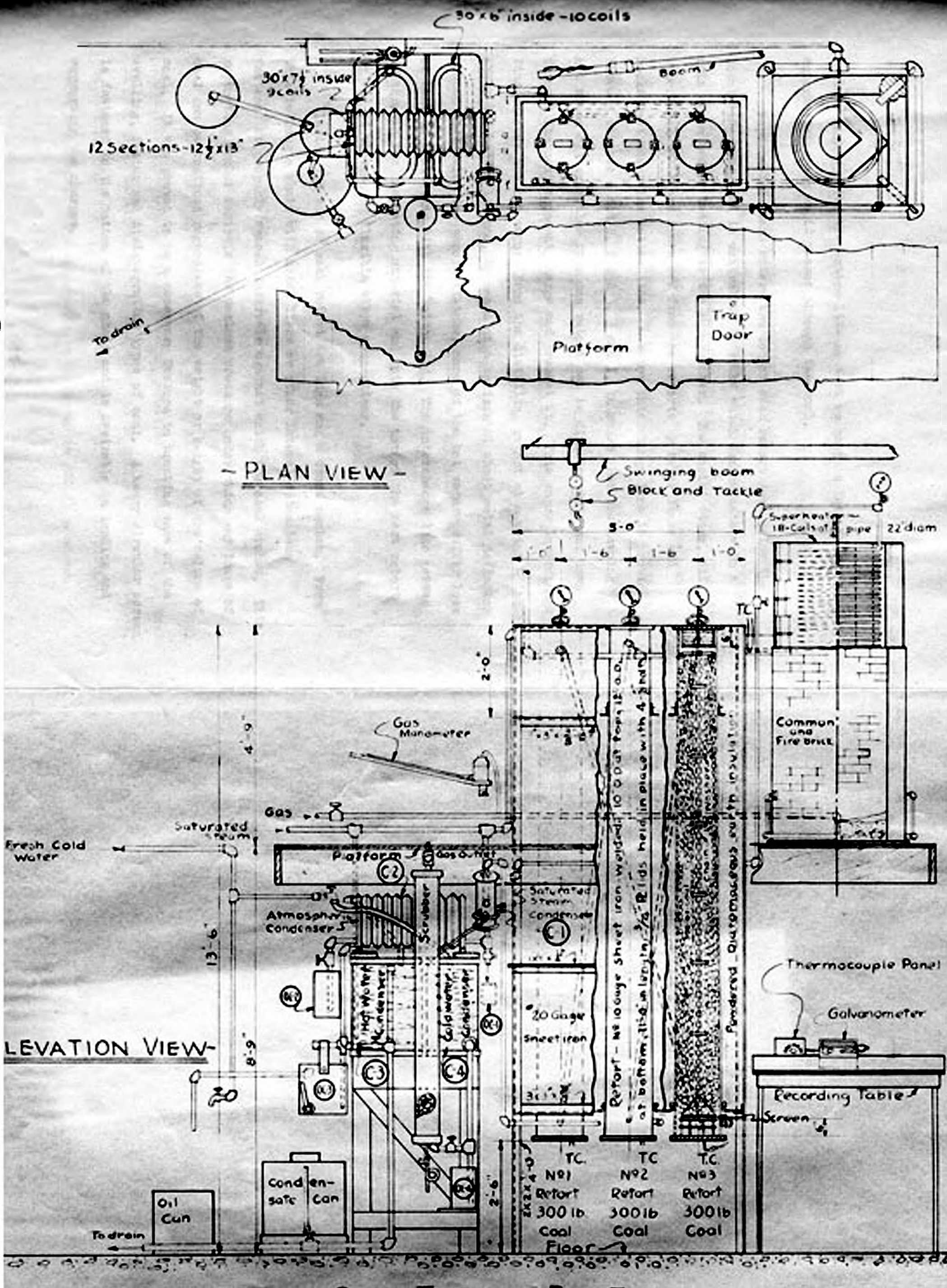
It is the hope of the present authors that their engineering studies described herein, as well as the previous smokeless fuels investigations of the School of Mines and Engineering, will be applied to solve this vast social and economic problem of our state.

DESCRIPTION OF COAL-TREATING PLANT

A plant was built for this study of such dimensions and capacity as to give commercial scale operating data and products. Therefore, it was decided best to erect a unit of three retorts large enough to provide the amount of gas that would be used in a 800 - 1000 population town in Utah. "Pea" (+ 3/4" - 1 5/8") and "Nut" (+ 1 5/8" - 3") coal was to be treated.

In the previous coal-processing studies by Messrs. Carter and Jacobsen, retorts were used of the same dimensions as those now operating in the largest low-temperature carbonizing plants in England, namely, 5 inches in diameter and 8 feet high. In the present investigation it was the purpose to obtain data from processing the larger "Nut" coal, and also save much of the heat which is lost by surface radiation from the smaller retorts. Consequently, 3 retorts were installed, each of approximately six times the volumetric capacity of the previous retorts.

The retorting plant is shown in the accompanying drawing, in elevation and in plan view, all parts of which are described. Three tapered steel retorts, 10"x12"x11' high are set 6-inches apart in a sheet steel housing filled with insulating earth. Top and bottom lids of steel platesprovided with grooves and gaskets are held in place by draw-bolts and maintain gas-tight closures. The top lids have insulating plugs 6-inches thick, bolted to their under side which prevent excessive loss of heat from the lids. The coal is supported on a perforated



COAL TREATING PLANT

3-RETORTS IN SERIES

COAL RESEARCH LABORATORY ~ UNIVERSITY OF UTAH - 1935 (½"=1') B.E.A.

table 6 inches above the bottom lids so that no heat is lost from the superheated steam as it passes through the coal.

Superheated steam enters the top of each retort just below the insulating plug, and is controlled by cocks which communicate with a main steam header leading to the superheater. The cooled steam, oil vapors and gases are drawn off from the retorts by vapor lines and cocks just above the bottom lids. A vapor interchange line is provided between retorts I and 2, 2 and 3, 3 and I, in order that the issuing hot steam and volatiles from one retort can be directed into and down through the next adjacent charge and preheat it. This vapor interchange line removes the hot vapors from the distilling retort at a point 4 inches above the bottom lid and, by means of a horizontal sheet metal deflector placed just below the vapor off-take, none of the hot vapors suffer loss of heat by contacting with the bottom lid. The interchange line passes up through the insulating material and into the top of the next retort by way of valves and flexible elbow connections.

Inside the top of each retort are lugs and a cross member. From this is hung a chain with metal discs or other lateral extensions fastened at properly spaced intervals against which the coal arches. This supporting member controls the maximum pressure under which any lumps of coal can be confined regardless of the weight or height of the column of coal. It was proved to be a necessary feature in treating some of the swelling, fusing and disintegrating types of coal. A heavy circular screen is fastened to the bottom of the chain and is desirable in loading and supporting the charges.

The steam superheater comprises a 3/4" steel pipe 100 feet long wound into a coil 22" in diameter and 26" high. It occupies the annular space between two concentric brickwalls. The heating is accomplished by burning gas in four combustion spaces below the coil, this being more convenient for the present purposes than firing with a stoker. The steam which has been dried and superheated by means of a steam-vapor heat exchanger, passes down through the coil counter-flow to the combustion gases. A valve and steam gage are used to adjust the flow of steam.

The steam and volatiles leaving the retorts are passed through a multiple-tube heat exchanger (C-1). This heat exchanger also functions as a steam separator and is operated at boiler pressure (100 lbs. gage). The oil vapors entering the tubes are caused to condense out all of the coal resins and all hydrocarbons that have boiling points below approximately 338°F. The condensate is collected in (OC-1). Most of this condensate is heavier than water and its removal by fractional condensation serves to make more easy the separation of the remaining oil and water by decantation. The hot volatiles and steam entering the heat exchanger give up much of their sensible heat to the steam which surrounds the tubes and thus superheats this steam to a considerable degree before it enters the main superheater.

The vapors and steam pass next into an atmospheric condenser (C-2) which is controlled so that no steam is permitted to condense in it. Most of the oil is liquified in this condenser and is entirely free from water. On cooling, this oil is quite solid and shows evidence of crystalizing waxes and resins. This condensate is collected in (OC-2) receiver.

Next, the remaining oil vapors, gases and steam pass into a condensing coil (C-3) which is surrounded with warm water. The warm water is necessary to prevent congealing of the waxy oil condensate. Most of the steam is also condensed herein, and the oil and water condensates are readily separated by the over-flow and skimming pipes shown at (OC-3).

The remaining light vapors then pass through a coil (C-4) surrounded by cold water, and therein the lightest oil is condensed. The condensate collects in receiver (OC-4). The incondensible gases then pass through a scrubber in which the light hydrocarbons, naphtha, are removed with a "wash oil", and thence to storage, or the gases are burned.

The temperatures are measured by chromel-alumel thermocouples (T.C) placed in the superheated steam line where the steam enters the retorts. This gives the maximum temperature of the coal at any time and this is the controlling factor in governing the yield and character of the smokeless fuel, oil, and gas. Thermocouples (T.C.) are also installed in the base of the retort at a position where they are surrounded by the steam and vapors just as it comes through the bottom layer of coal. Thus the temperature of the 'thermally remote' parts of the charge are always under observation which insured accurate control of rates and temperatures of distillation at all times.

Figure I

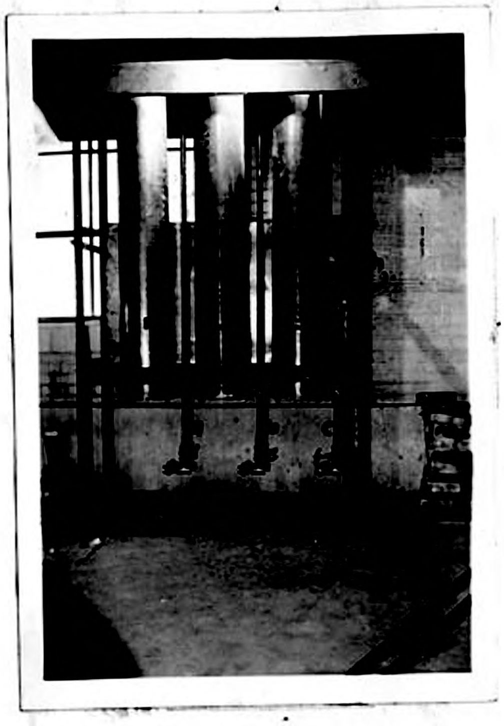


Figure 2

The two photographs appearing above show the three retorts in place before the diatomaceous earth insulating material was placed around them. Figure I is a view above the loading platform. This view serves to illustrate the method of supporting the retorts and the pipe connections to them. The line marked (a) is the superheated steam line, and (b) the saturated steam line. Three valves are placed in the superheated steam lines as shown, one leading to each retort. Three valves are also placed in the saturated steam line, one for each retort, one of which is shown at (f).

One important feature of design is that shown at (h). Any expansion of the retorts or pipe connections will be taken up at this point by the rotation of the elbows and thereby avoid any damaging stresses due to expansion. Connections made between retorts employ the same principle. This is of particular advantage in the lines that would otherwise break or be injured due to different expansion rates of the two interconnected retorts.

Figure 2 is a view of the retorts as they appear below the platform. Up to this point in the construction no connection had been made to the condensing system, nor was there a connection from retort No.I to retort No. 3. The 1-inch pipes marked a, b, and c, are the vapor lines leading from the respective retorts through a main line to the condensing system. Three cast iron valves, d, e, f, are shown which control the flow of vapors from each retort into the vapor line and condensing system. At the back of the retorts is shown the sheet steel (h) that was used to house the retorts and hold the insulating material in place.

Figure 3

Figure 4

The two above pictures show those parts of the plant below the platform. Referring to Figure 4, the complete housing around the retorts is labeled (a), the bottom lids (b), (c), and (d). Lid (d) has been taken off to allow removal of the charge. The main vapor line (e) is shown connected from the retorts to the steam trap and thence to the condensers (f) in Figure 3. At (f) in Figure 3, the heavy oil condensate is drawn off. The vapors go from (f) to the final condensing system (g) and (h). The steel cylinder (i) is the scrubber which is used to remove naphtha from the gas. The pipe (j) is an outlet from condenser (h) to the **drain.** (k) is the light oil outlet. Oil recovered here is about 50% gasoline distillate.

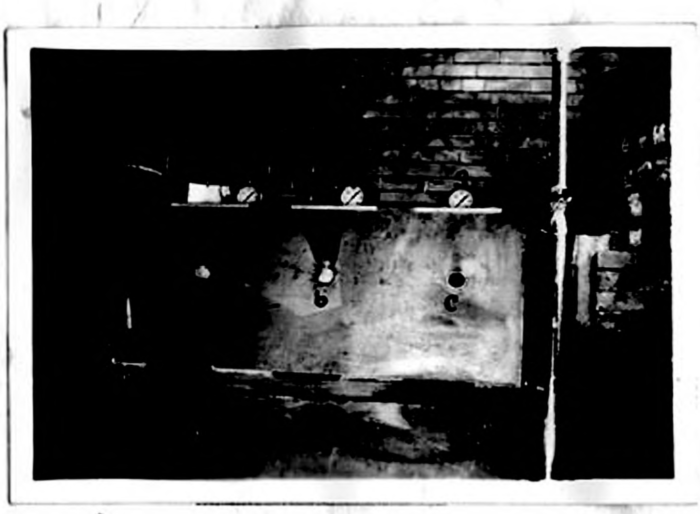


Figure 5

Figure 6

In Figure 5 the openings (a,b,& c) to the valves on the super-heated steam line can be seen. The valve marked (d) in Figure 5 is the valve from the steam trap into the superheater. Gages (e,f, & g) are used to measure retort pressure. The line (h) serves to by-pass the superheated steam to the atmosphere. The view of the retort lid (i) illustrates the method of holding the six inches of insulation onto the under side of the lid.

Referring to Figure 6, a thermocouple is located at point (a) to measure the temperature of the superheated steam as it enters the retorts. Ports to the combustion chambers are shown at (b). Burners opening into the ports are mounted on 2-inch surrounding the superheater. The circular part holds the superheater coil and the square part the combustion chambers.

VII

Figure 7

Figure 8

Figure's 7 and 8 show a charge of smokeless fuel coming from the retort. Both pictures are of **similar charges.** They indicate a considerable degree of softening and cohesion of this coal. The compression of the coal lumps is controlled by the large link chain containing lateral extensions at spaced intervals along its length as shown by (a) Figure 7.

Althouth considerable fusion is shown to have taken place in this charge, distillation was completed throughout, and the finished product was entirely smokeless.

Figure 9

The above print displays a retort partly loaded and the chain supporting means extending through the charge. The lateral extensions can be seen on the chain.

TV

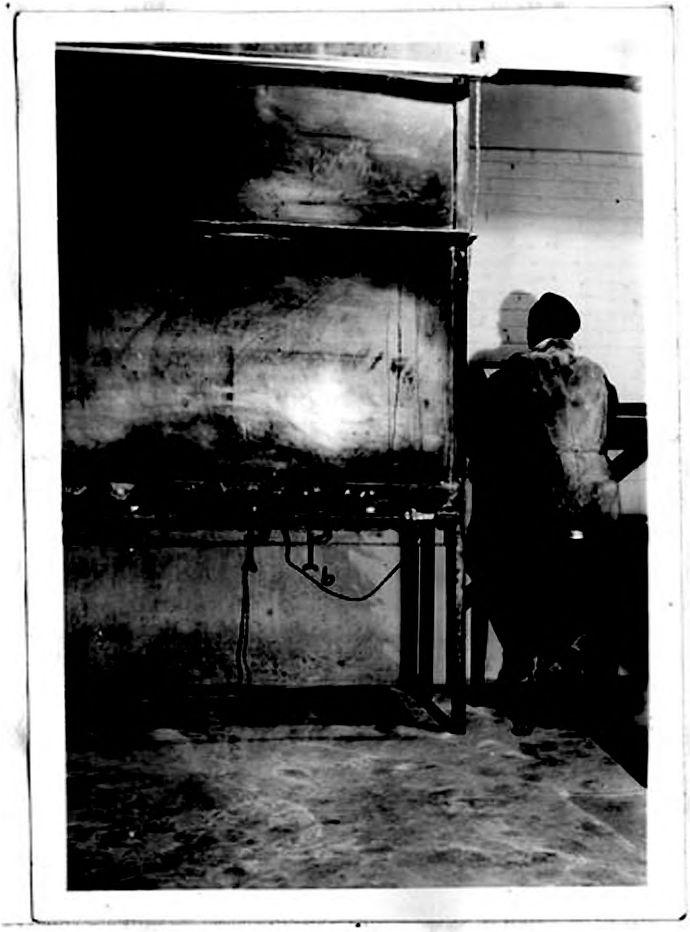


Figure 10

All records of plant operation were taken from the table shown in Figure 10. A thermocouple is shown at (a), and the thermocouple connection (b) leading from the bottom of retort No. 3 to the potentiometer on the recording table.

Figure 11

In Figure 11, the front of the condensing system is seen. The container (a) is used to measure the condensed steam. At (b & c) the oils that were lighter than water were collected. The outlet pipe leading from the entire condensing system to the drain is shown at (d). The various types of heating appliances used to test the smokeless fuels obtained are shown in this picture.

XI

PLANT RUN NO. I

Preliminary Run.

To determine the mechanical success of the plant, also to obtain data on the nature of the smokeless fuel and on heat requirements.

Numbers 1 and 2 retorts were each charged with 300 pounds of "Aberdeen" coal. "Pea" coal was used which had previously been tested in the small batch (16-pound) carbonizer, which showed the coal to become partly plastic and cause the lumps to compress together to a slight degree, but to give dense lumps of smokeless fuel of attractive appearance. No internal support was provided for the coal lumps, as in the previous studies by George Carter and Clark Jacobsen, and, therefore, the lumps of coal were at all points in the retort under the compressive weight of the super-posed column of coal. Consequently, the coal in each retort compressed into dense cylindrical lumps the diameter of the retort, which tended to retard the flow of steam through the retorts during portions of the period. Some sections of the smokeless fuel cylinders discharged from the retorts were as much as three feet long. These cylindrical lumps were, however, found to be perfectly smokeless in combustion at their very centers, as well as at the surfaces. The treated coal was easily dropped from the retorts as there was no tendency to adhere to the retort walls.

The superheated steam cocks were easily opened and closed while red hot. The top and bottom lids to the retorts were easily maintained gas-tight throughout the runs. The superheater was easily regulated to maintain a constant flow of steam at 1200° F. The condensing system was taxed to capacity while cooling the combined superheated steam, the volatiles from the coal, and the dry-quenching steam.

Superheated steam at 1200° F. was passed into the retorts at approximately 100 pounds per hour for seven hours. After the first four hours, the superheated steam was passed directly into No. 2 retort, the charge having been undergoing preheating from the steam and volatiles issuing from No. 1 retort. When the bottom coal of the retorts reached 760° F., saturated steam was introduced at the top of the retorts which completed the distillation and served simultaneously to dry-quench the treated coal. In this run, over 1100 pounds of steam were used for distilling and dry-quenching operations, but this quantity was excessive due to heat losses from radiation and conduction during periods when the distilling slowed down as the charge began to compress, also because of the excessive bottom temperature before the dry-quenching was begun, and because No. 1 retort and charge was not preheated.

The yield of smokeless fuel was 425 pounds, or 70 per cent of the weight of coal charged. Gas yield was not measured but previous low-temperature studies by Carter showed this coal to give 900 cubic feet (3,000 cubic feet per ton) of 1000 - B.T.U. gas. The run yielded 9.0 gallons of crude oil, or 30 gallons per ton of coal.

It was determined that this coal should be distilled while using the internal coal support unless larger lump sizes were used, in which case, the support would not be desirable. Much time could be saved and larger retort capacity would be insured.

PLANT RUN NO.2

To compare the smokeless fuel obtained from coal of "Nut" size with that from "Pea" coal when distilled under approximately the same conditions of Run No.I, also to compare heat consumption and operating data:

No.I retort was charged with 230 pounds of "Nut" size Aberdeen coal and on top of this there was charged 30 pounds of "Pea" coal. The small size coal was placed on top of the charge in order to observe the degree of compression and agglomeration when this coal was under less downward weight than in the previous run. No internal support was provided for either the small or the large size lumps. Only slight agglomeration or cohesion of the lumps occured, but the continuous weight and pressure on all sides of the different sized lumps caused them to become quite dense.

No difficulties were experienced with the superheated steam cocks or with the gas-tight sealing of the retort lids. In this run, no pressure developed inside the retort due to compacting of the coal mass and restricting the flow of steam.

The steam was superheated to 960°F. before introducing it into the retort. Therefore, neither the coal nor the retort was preheated above room temperature. The steam temperature was increased gradually to 1200° F. in 2 hours 50 minutes, at which time, the superheated steam was shut off and the dry-quenching steam was introduced as the coal at the bottom of the retort had reached 700°F. The dry-quenching was completed in 90 minutes. The excessive amount of steam used was due to distilling without preheating the coal or the retort above room temperature before introducing the superheated steam, also owing to the low temperature of the steam until near the end of the run.

The yield of smokeless fuel was 170.5 pounds or 65.5 per cent by weight of the coal charged. It comprised the following sizes: + 1½" - 56.0 pounds; - 1½" + 3/4" - 80.0 pounds; -3/4" + ½" - 13.0 pounds; - ½" - 21.5 pounds. Hand screening was applied which probably caused some degradation of the smokeless fuel lumps over what would have resulted from standard mechanical screening practice. The gas and oil yields were approximately 3000 cubic feet and 30 gallons, respectively, per ton of coal.

PLANT RUN NO. 3

The object of this run was to observe results of distillation treatments on a Utah sub-bituminous coal:

No. I retort was charged with 248.5 pounds of Coalville coal of 1 5/8" + 3/4" size. Steam superheated to 800°F. was introduced at 2 pounds per minute, and its temperature raised to 1200°F. in one hour. In three hours, the coal at the bottom of the retort had reached 625°F., whereupon the superheater fire was stopped and the steam continued to flow, thus completing the distillation and the dry-quenching of the treated coal.

No swelling or cohesion of this coal took place and no back pressure developed. However, for a short period, the steam temperature rose to above 1200°F. and caused a large volume of water gas to form which developed a higher retort pressure and, momentarily, caused a greater flow of volatiles than the condensers would handle. Better circulation of the condenser cooling-water was found to greatly increase the condenser capacity.

A very attractive smokeless fuel was obtained which was 59 per cent of the weight of the coal charged. The product sizes averaged considerably smaller than the coal charged, but it was determined to be of the sizes used in the anthracite markets, excepting the "Egg" size. Gas yield was not measured as it had previously been carefully determined under identical conditions in the studies of Messrs. Carter and Jacobsen. The oil yield was approximately 22 gallons per ton of coal. The steam consumption was approximately 500 pounds, it being excessive due to lack of preheating, low initial steam temperature, etc.

PLANT RUN NO.4

The object of this run was to take data on heat required, and operating characteristics while running the three retorts in series with Carbon County coal:

No.2 and No.3 retorts were each charged with 271.0 pounds of "Aberdeen" coal sized to 1-5/8" + 3/4". No.I retort was full of treated coal from a previous run, and the re-charging of this retort was delayed until after the distillation was under way in retorts No. 2 and No.3. Superheated steam at 1200° F. was then introduced into No.2 retort, without preheating the retort and contents as would be the case in a continuous run of the three retorts. The steam and volatiles leaving the bottom of the retort No.2 were directed through the heat-interchange line into the top of No.3 retort whereby the charge and the retort were preheated.

After each three-hour interval the superheated steam was switched into the next retort which had been undergoing preheating, after which the saturated steam was directed into the distilled charge to accomplish the dry-quenching of the treated smokeless coal. It was not necessary to pass superheated steam into the retorts until the bottom coal was completely distilled. It had previously been shown in the U.S. Bureau of Mines oil shale and coal-treating studies, as well as in the studies of Messrs. Carter and Jacobsen, that the dry-quenching steam will complete the distillation of the bottom third of the coal charge by transferring the "stored" heat remaining in the upper treated coal down into the bottom portion of the coal charge.

In this plant run it was demonstrated that with a given flow of superheated steam at 1200° F. that the distilling period was 3 hours, but if the charge was preheated then the distilling period could be reduced to 2½ hours. The dry-quenching was completed in 2 hours. Consequently, with the preheating requiring 2½ hours, the complete cycle would be approximately 7½ hours. By using higher steam flow it should be possible to complete the cycle in 6 hours, thereby treating 4 batches of 300 pounds of coal each per 24 hours in each retort.

PLANT RUN NO.5

The object of this run was to obtain the amount of heat involved in heating the retort walls and maintaining them at the treating temperatures during a normal distillation:

No.I retort was selected as it was substantially at room temperature. The lids were made tight, and the superheater started. The steam was by-passed until it had reached an average temperature used in the low-temperature carbonizing tests, namely, 1100° F., and was then turned into the top of the empty retort. The temperatures were read at regular intervals at the top and bottom of the retort. With 2.25 pounds per minute of superheated steam flowing into the retort it required 100 minutes for the bottom thermocouple to reach 735°F.

From these data it was concluded that approximately one-half of the useful distilling heat of the superheated steam used in carbonizing, that is, the heat in the steam above 735° F., accumulates in the walls of the retorts. These data showed further that considerable heat economy is obtained by preheating the charge of coal and the retorts by means of issuing volatiles and steam coming from another charge undergoing distillation, or by the use of the sensible heat of the treated coal in the top of the retorts to heat the retort walls and distill the coal in the bottom of the retorts.

PLANT RUN NO. 6

The object of this test was to determine the operating results of the plant, also the characteristics of the smokeless fuel from both "pea" and "nut" coals from Carbon County while distilling under normal conditions, but using the longitudinal coal support in the retort:

(A delegation of Carbon and Emery County officials witnessed the operations.)

One of the retorts was charged with "Mohrland" coal consisting of 265 pounds of "pea" coal, on top of which was placed 50 pounds of "nut" coal. The longitudinal support was placed in the center of the charge in order to insure uniform pressure on the coal lumps throughout the retort. Superheated steam at 1100° F., flowing at 2.5 pounds per minute, was used without preheating the retort and coal. The distillation was completed in 2.25 hours, and the dry-quenching in 2 hours.

No retort leakage or other mechanical defects appeared. In this run, the steam flow was less stricted as was indicated by the low retort pressure at all times. The operation was without interruption and very successful.

The large and the small lumps of treated coal had knitted together slightly but compression was well controlled by the coal supporting means, so that the lumps readily separated and formed a very attractive smokeless fuel. The larger lumps showed some deep cracks that had started to form but had finally solidified.

PLANT RUN NO. 7

The object of this run was to obtain operating results of plant, steam consumption, and smokeless fuel data from treating another representative Carbon County coal:

Retort No.I was charged with 265 pounds of "Mohrland" coal from the Western Fuel Company. The coal was sized to pass through a 2-inch screen and pass over a 3/4-inch screen. Previous tests of the coal in the small batch (16-pound) carbonizer showed that the coal was of the type that would swell and soften considerably while being distilled. It was evident that special means must be taken to produce the best quality of smokeless fuel and, therefore, the longitudinal coal support was placed in the center of the retort while charging in order to control the degree of compression of the coal. Also the coal was graded and charged with the largest lumps at the bottom of the retort and the smallest at the top, thus applying the greatest pressure on the largest lumps.

Superheated steam at 790°F. was turned into No.I retort. The steam flow was maintained constant at approximately 1.5 pounds per minute. After charge No.I had been distilling for 2.5 hours No.2 retort was charged and the vapors issuing from No.I were passed down through charge No.2 - to preheat the fresh charge. Forty-five minutes later, charge No.I was completed and the superheated steam, now at 1100°F. was turned into No.2 The second charge was completed in 2.5 hours. Dry-quenching of both charges continued for about 3 hours.

The total steam, superheated and dry-quenching steam, consumed was 1.8 pounds per pound of coal. This amount could have been reduced considerably by preheating No.I charge, also if the superheated steam had been at 1100°F. when introduced into charge No.I. The smokeless fuel lumps were dense and very attractive in appearance.

PLANT RUN NO. 8

The object of this run was to obtain data on steam consumption when:

(1) Preheating No.I retort empty, then distilling charge of "Pea" coal without preheating it;

(2) Preheating No.2 retort and charge of "Pea" coal with vapors issuring from No.I retort undergoing distillation;

(3) Preheating No.3 retort containing "Nut" coal with vapors issuing from No.2 retort undergoing distillation.

Superheated steam was passed into retort No.I empty for 3 hours starting at 750°F. and increasing to 1190°F. Then retorts No.I and 2 were charged with 315 lbs. of Coalville "Pea" coal and the superheated steam was introduced into No.I and the issuing vapors and steam were directed into No.2 charge. The superheated steam at 1150°F. was regulated to maintain a flow of 120 lbs. per hour for nine hours until the run was completed.

At the end of 3 hours 10 minutes the bottom of No.I charge had reached 715°F. so the superheated steam was diverted into No.2 retort. The issuing steam and vapors from No.2 were directed into No.3 retort which had been charged with 312 lbs. of Coalville "Nut" coal. At the end of a period of 3 hours the bottom of No.2 charge had passed 780°F. so the superheated steam was diverted into No.3 retort. After another 3-hour period, the bottom of No.3 charge was at 775°F., whereupon, the superheated steam was shut off. The three charges were dry-quenched simultaneously and required approximately 4 hours, an hour longer than the distilling period, owing to the fact that only one-half of the flow of steam was used as in the distillation.

The distillation and preheating steps required 1.15 lbs. of steam per pound of coal, and the dry-quenching 0.5 lb. of saturated steam. The superheated steam temperature was kept from exceeding 1150°F. in order to prevent the rapid evolution of water gas which made difficult the condensation of the steam and oil vapors. It had previously been demonstrated that the smokeless fuel formed by this treatment of coal with superheated steam will combine rapidly with steam heated above 1150°F. in accordance with the following reactions:

$$C + H_2O = CO + H_2$$

$$C + 2H_2O = CO_2 + 2H_2$$

Consequently, for each molar volume of steam that reacts with the carbon there are from 1½ to 2 mols of water gas formed. Obviously there is an advantage in causing this gas to form in that it will be at 1150° F. and, per unit volume, it will distill the same amount of coal as an equal volume of superheated steam at 1150° F. However, the condensing system was not adequate to efficiently cool the vapors when carrying any excess gas over that produced by the low-temperature distillation. It was interesting to note the quick increase in volume of gas by increasing the steam temperature above 1150° F., and it indicates that a cheap source of low - B.T.U. industrial gas can be formed from the top layers of small sized treated coal in the retorts before dry-quenching is begun.

The smokeless fuel from this plant run averaged considerably smaller in screen sizes than the raw coal as charged. However, the granular product formed by disintegration of the distilling coal contained most of the sizes of domestic fuel used in the anthracite coal markets. The product was rather friable but was bright and clean, also its ignition and burning properties were very good, so the authors believe it should become a popular and satisfactory domestic smokeless fuel. The oil and gas yields were not accurately determined, but the distillation conditions applied can be depended upon to give the same yields as in the Master's Thesis of George W. Carter, 1934.

PLANT RUN NO. 9

The object of this run was to obtain data on plant operating characteristics and on the smokeless fuel while distilling "Nut" coal at a faster rate:

Previous plant runs had demonstrated the need for preheating the coal and retorts in order to minimize the consumption of superheated steam. Also, data were obtained which prove that a large percentage of the available heat of the superheated steam may be saved by discontinuing the flow of superheated steam before the distillation zone has reached the bottom of the charge, and finishing the steam distillation with saturated steam which simultaneously served to dry-quench the treated coal. Therefore, it seemed desirable to make a plant run at a very rapid rate in order to minimize the heat lost by absorption in the retort walls and surrounding insulation. The internal coal support was also used in order to insure continuous premeability of the coal charge to the flow of steam.

No.2 retort was filled with 300 lbs. of "Mohrland", Carbon County, Utah, coal of "Nut" size. Superheated steam at 985°F. was introduced into the retort at the rate of 155 lbs. per hour. In 1 hour 30 minutes the bottom of the coal had reached 690°F., so the dry-quenching was started while using the same flow of steam. The run was completed, distillation without preheating, and dry-quenching in 3 hours total time. The total steam consumption was 460 lbs., of which 250 lbs. was superheated steam.

COMPARATIVE EFFICIENCIES OF
SMOKELESS FUEL AND RAW COAL IN HOUSE HEATING APPLIANCES

Object of These Tests

The object of these tests was to determine the relative efficiencies of combustion of raw coal and smokeless fuel (low-temperature coke) when burned in three standard house heating appliances; a fireplace, a cook stove, and a heatrola under average firing conditions.

Description of Equipment

A fireplace, shown in the detailed drawing, Figure 13, was built in the Coal Research Laboratory at the University of Utah. This fireplace was designed and constructed as much as possible like a typical fireplace found in the average home.

The new cook stove, which was donated to the Fuels Laboratory by Mrs. Alice Merrill Horne of the "Smokeless Fuel Federation of Utah", is a standard form of kitchen range manufactured by the Oakland Foundry Company of Illinois.

The heating stove, a No. 72 "Estate Heatrola", was manufactured by the Estate Stove Company of Hamilton, Ohio. The studies with this heating stove were made at the residence of Mr. L. F. Anderson in Salt Lake City.

DETAILED DRAWING OF FIREPLACE

COAL RESEARCH LABORATORY

UNIVERSITY OF UTAH

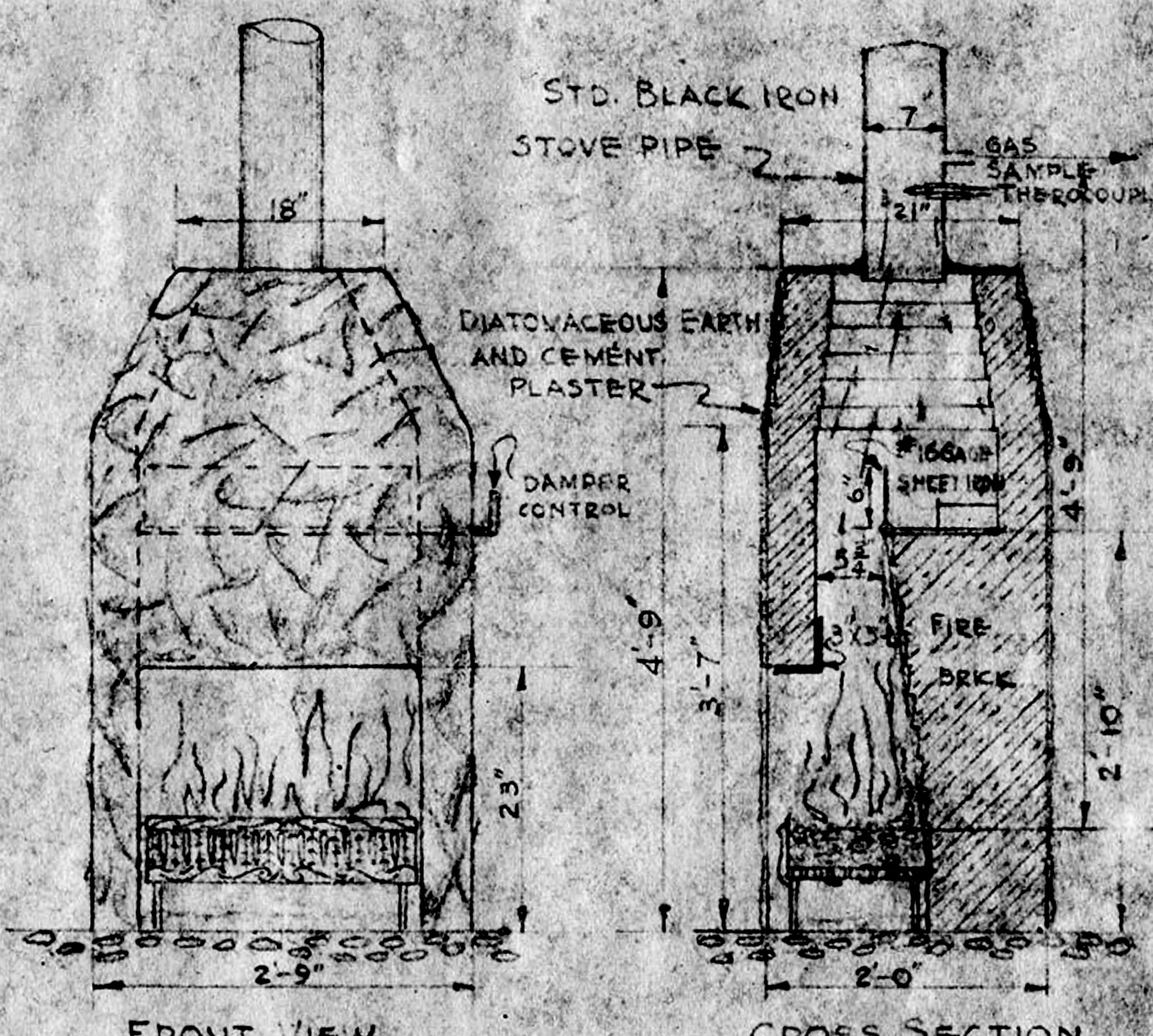


FIG. 18

Method of Testing Appliances

The fireplace was equipped with a thermocouple and gas sampling tube in the chimney, approximately 57 inches above the fuel bed as shown in Figure 13. A uniformly distributed fire was built in the fireplace and enough smokeless fuel was added to build up a fuel bed about 4 inches deep. When the fire had been allowed to burn long enough to thoroughly heat the walls of the fireplace, and the rate of burning was constant with the chimney damper closed, 5 pounds of the fuel was added. The chimney damper was opened for about 10 minutes to aid in igniting the newly added fuel and then it was closed. A sample of the flue gas was pumped into the Orsat gas analyzer about 2 minutes after adding the smokeless fuel charge and was analyzed immediately. Samples were also taken every 15 minutes thereafter, also temperature readings, until the fuel bed was reduced to the same thickness as it was before adding the fuel. The ashes were shaken down just before the fuel was added. The time for the test required approximately 3 hours and 30 minutes. The air supply was regulated in each test to burn the fuels at the same rate. The temperatures of the flue gases were read by means of a Leeds-Northrup potentiometer which was connected to the chromel-alumel thermocouples placed in the centers of the chimneys.

The sample calculations show the averages of these readings as taken.

The same method of testing was used while burning the raw coal, but it was necessary to leave the damper open for a much longer period, in order to allow the yellowish oil-laden smoke to pass up the chimney.

The same method of testing was used on both the cook stove and the Heatrola.

During the tests with the cook stove, the temperature of the grate was taken approximately every 10 minutes. The samples and temperatures of the flue gases were taken at a point 57 inches above the fuel bed.

The Heatrola tests were conducted in a residence, but the same firing conditions were applied. The temperatures and flue gas samples were taken from a point 60 inches above the fuel bed ust around the elbow of the stove pipe and about 4 feet from where it connected into the brick chimney.

Sample Calculations

Showing the Comparative Efficiencies of

Smokeless Fuel (Low-Temperature Coke) and Raw Coal.

DATA:

The following data are averages taken from a number of heating appliance tests with an Orsat analyser.

Appliance	CO_2 Per cent	O_2 Per cent	CO Per cent	N_2 Per cent	Flue Gas Temperature °F.	Grate Temperature °F.	
Fireplace	2.16	18.56	0	79.28	204		S.F. Aberdeen
	.633	20.6	Trace	78.77	175		Coal Aberdeen
Cook Stove	2.83	17.6	0	79.57	210	958	S.F. Aberdeen
	3.1	17.6	Trace	79.3	243	1001	Coal Aberdeen
Heatrola	9.3	9.9	1.8	79.0	405		S.F. Aberdeen
	9.66	9.81	.6	79.93	425		S.F. Coalville
	9.4	10.8	1.65	78.15	520		Raw Coal Aberdeen

(S.F. - Smokeless Fuel)

In the following calculations, it is assumed that the relative rate of burning of the coal and smokeless fuel was exactly the same and is based upon one pound of coal. In the actual tests, the rate of burning was very nearly the same. The damper settings were left exactly the same except in the case of smoking fuel, where the flue dampers were opened just enough to allow all the smoke to go up the chimney.

Proximate Analysis(4.) of the Fuels Used in the Tests.

	Aberdeen		Coalville
	Raw	S.F.	S.F.
Moisture	3.2	0	0
Fixed Carbon	50.8	75.9	57.3
Volatile	39.7	17.0	37.0
Ash	6.3	7.1	5.7
Sulphur	.53	.55	1.1
B.T.U. per Pound	13,300	12,900	13,750

Ultimate Analysis from Proximate(5)

Weight - percentages

$$H = V \left(\frac{7.35}{V+10} - .013 \right)$$

$$C = 0.9\,(V-14)$$

(4.) Engineering Factors Relating to the Production of Smokeless Fuel, Oil and Gas From Rocky Mountain Coals by Low-Temperature Carbonization", by G. W. Carter, Master's Thesis in Mechanical Engineer, University of Utah, 1934.

(5) "Elements of Heat-Power Engineering", by Hirshfeld and Barnard, 1915.

$$N = 2.10 - 0.012V$$

Aberdeen Raw Coal

$H = 5.35$ Total: $C = 50.8 + 22.15$

$C = 22.15$ $= 72.95$

$N = 1.624$

Aberdeen Smokeless Fuel

$H = 4.40$ Total: $C = 75.9 + 2.7$

$C = 2.7$ $= 78.6$

$N = 1.896$

Coalville Smokeless Fuel

$H = 5.31$ Total: $C = 57.3 + 20.7$

$C = 20.7$ $= 78.0$

$N = 1.655$

Ultimate Analysis as Calculated From the Proximate

FUEL	Per Pound of Coal						
	C	H	O Difference	N	S	Analysis Ash	Analysis Moisture
Aberdeen Raw	72.95	5.35	10.046	1.624	.53	6.3	3.2
Aberdeen S.F.	78.6	4.40	7.454	1.896	.55	7.1	0
Coalville S.F.	78.0	5.31	8.235	1.655	1.1	5.7	0

Efficiency of Aberdeen Raw Coal

INPUT:

Heat in the coal

Fireplace - 1 pound of coal x 13,300 B.T.U. = 13,300 B.T.U.

Cook Stove - 1 pound of coal x 13,300 B.T.U. = 13,300 B.T.U.

Heatrola - 1 pound of coal x 13,300 B.T.U. = 13,300 B.T.U.

OUTPUT:

Heat loss in stack gases

Carbon in Coal

Fireplace = 1 x .7295 = .7295 Pound

Cook Stove = .7295 "

Heatrola = .7295 "

Mols Carbon in Gases

Fireplace = $\frac{.7295}{12}$ = .0607 Mols

Cook Stove = .0607 "

Heatrola = .0607 "

Mols of Dry Stack Gases

Fireplace .0607 x $\frac{1000}{.633}$ = 9.6 Mols dry gas

Cook Stove .0607 x $\frac{100}{3.1}$ = 1.96 " " "

Heatrola .0607 x $\frac{100}{11.05}$ = .549 " " "

Mols of CO_2

Fireplace	9.6	x	.00633	=	.0607	Mols CO_2
Cook Stove	1.96	x	.031	=	.0607	" "
Heatrola	.549	x	.094	=	.0516	" "

Fireplace	O_2, N_2, CO	=	100 - .633	= 99.367	Percent
Cook Stove	" " "	=	100 - 3.1	= 96.9	"
Heatrola	" " "	=	100 - 9.4	= 90.6	"

B.T.U. Per Mol(6)

	175°F. Fireplace	243°F. Cook Stove	520°F. Heatrola
CO_2	1050	1800	4350
O_2, N_2, CO	750	1250	3200
H_2O	950	1630	3750

Losses in B.T.U. CO_2

Fireplace	.0607	x	1050	= 63.8	B.T.U.
Cook Stove	.0607	x	1800	= 109.30	B.T.U.
Heatrola	.0516	x	4350	= 224.2	B.T.U.

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(6) "Fuels and Their Combustion", by Haslam and Russel, Page 210, 1926.

Losses in O_2, N_2, CO - B.T.U.

Fireplace	.99367	x	9.6	=	9.54	Mols
Cook Stove	.969	x	1.96	=	1.90	"
Heatrola	.906	x	.549	=	.497	"

Fireplace	750 B.T.U per mol	x	9.54	=	7,150	B.T.U.
Cook Stove	1250 B.T.U per mol	x	1.90	=	2,375	B.T.U.
Heatrola	3200 B.T.U per mol	x	.497	=	1,590	B.T.U.

(a) Total heat in dry stack gases

Fireplace	63.8	+	7,150	=	7,213.8	B.T.U.
Cook Stove	109.3	+	2,375	=	2,484.3	B.T.U.
Heatrola	224.2	+	1,590	=	1,814.2	B.T.U.

Heat carried by water vapor from moisture and from hydrogen in coal.

H_2O from Moisture in Coal

Fireplace	1 x .032	=	.032	Pound
Cook Stove		=	.032	"
Heatrola		=	.032	"

H_2O from Hydrogen in Coal

Fireplace	1 x .0535 x 18/2	=	.481	Pound
Cook Stove		=	.481	"
Heatrola		=	.481	"

Total Losses from H_2O

Fireplace	$.032 + .481$	$= .513$ Pound
Cook Stove		$= .513$ "
Heatrola		$= .513$ "

(b) Sensible Heat in Water Vapor

Fireplace $\frac{.513}{18} \times 950 = 27.1$ B.T.U.

Cook Stove $\frac{.513}{18} \times 1630 = 46.5$ B.T.U.

Heatrola $\frac{.513}{18} \times 3750 = 107.0$ B.T.U.

(c) Heat of Vaporization

Room Temperature 70°

Fireplace $.513 \times (175 - 70) = 53.8$ B.T.U.

Cook Stove $.513 \times (204 - 70) + 975 + .47(243 - 204) = 578.0$ B.T.U.

Heatrola $.513 \times (204 - 70) + 975 + .47(520 - 204) = 644.0$ B.T.U.

(d) Undeveloped Heat Due to CO

$$\frac{CO}{CO_2 + CO} \times C \times 10160 = \text{loss in B.T.U.}$$

Fireplace 0

Cook Stove 0

Heatrola $\frac{1.65}{9.4 + 165} \times .7295 \times 10160 = 110.5$ B.T.U.

Total Stack Losses = (a) + (b) + (c) + (d)

Fireplace	7,213.8	+	27.1	+	53.8	+	0	=	7,294.7	B.T.U.
Cook Stove	2,484.3	+	46.5	+	578	+	0	=	3,108.8	B.T.U.
Heatrola	1,184.2	+	107.0	+	644	+	110.5	=	2,675.7	B.T.U.

TABLE I

Efficiencies of Appliances

All losses other than flue gas losses are considered as useful heat.

Appliance	Raw Coal Per cent	Aberdeen Smokeless Fuel Per cent	Coalville Smokeless Fuel Per cent	Per cent Increase in Efficiency
Fireplace	45.9	76.1		65.9
Cook Stove	77.3	80.5		4.14
Heatrola	80.0	85.4	83.4	S.F. 6.75 C.S.F. 4.25

S.F. - Aberdeen Smokeless Fuel

C.S.F. - Coalville Smokeless Fuel

B.T.U. Losses in Stack Gases

Appliance	Aberdeen Raw Coal	Aberdeen Smokeless Fuel	Coalville Smokeless Fuel
Fireplace	7,294.7	3,050.6	
Cook Stove	3,108.8	2,718.6	
Heatrola	2,675.7	1,889.6	2,287.9
B.T.U. in 1 Pound Coal	13,300	12,900	13,750

DISCUSSION OF BURNING CHARACTERISTICS OF SMOKELESS FUEL AND BITUMINOUS COAL

One very outstanding characteristic that was noted throughout all the combustion tests was that there was absolutely no smoke given off at any time by the smokeless fuel. This was also carefully ascertained by conducting tests with each of the stoves and the fireplace in which no connection was made between stove pipes and the outside flue. All of the combustion gases were allowed to pass directly into the room. These gases were then dissapated through opened sky light windows. In testing the raw coal, it was very necessary to connect the pipes to the flue, because when it was tried otherwise, the room would become so filled with smoke in a few moments that a person could not stay in the room. There was no other determination made upon the smoke densities and determinations because these tests were conclusive, also actual measurements were made last spring by Messrs. George W. Carter and S. Clark Jacobsen(7)

Table I shows the actual comparative efficiencies of the smokeless coal vs the raw coal. In the fireplace, the smokeless fuel was found to give a heating efficiency of 30.2% more than the raw coal. In the cook stove, the smokeless fuel from Aberdeen coal was found to give a

(7) "Engineering Factors Relating to the Production of Smokeless Fuel, Oil and Gas From Rocky Mountain Coals by Low-Temperature Carbonization", by G. W. Carter, Master's Thesis in Mechanical Engineering, University of Utah, 1934.

heating efficiency of 3.2 per cent greater, and in the Heatrola, 5.4 per cent greater than the raw coal, and with the Coalville smokeless fuel, 3.4 per cent greater heating efficiency than with the raw Aberdeen coal.

In Mr. L. C. Karrick's fuels studies at Pittsburgh with the U.S. Bureau of Mines, 1924 to 1926,[8] very extensive tests were made on raw Utah coal and on smokeless Utah coal as they were produced in the present plant. These tests were made in a standard house heating steam boiler.

The boiler was set up on a platform scale, so as to determine the actual losses of weight of the fuels as they were being consumed. Very accurate data were secured from the U.S. Weather Bureau on the annual climatic conditions of Northern Utah for the average year. From this information the engineers adopted three rates of burning such as would be applied in, (1) the mild spring and fall weather, (2) in the 100 days of winter weather, and (3) in the 10 days of frigid weather. Tests were made at each of these rates on both raw coal and on the treated Utah coal. Each test continued for 3 days, day and night, to simulate residence firing conditions as nearly as possible. They even included banking the fire at night.

Average results of these tests were as follows:

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(8) Data withheld from publication at the request of L. C. Karrick.

Thermal Efficiency (Heat transferred to water)

Smokeless Fuel			Raw Coal			
1.	2.	3.	1.	2.	3.	4.
59.3	65.3	61.1	45.6	49.0	44.6	47.4

This gave a heating value of the smokeless fuel of 1.3 times the heating value of the raw coal by weight.

The space occupied by the smokeless fuel was 1.66 times that of the same weight of coal.

The calorific value of the smokeless fuel was .78 that of the same volume of coal.

The raw coal gave off smoke until 80 per cent of the coal by weight was burned.

Curves for the entire test were plotted using figures for the heat absorbed in the water as ordinates, and figures for the rate of burning in pounds of fuel per hour, as abscissae. The curve for the smokeless fuel was substantially a horizontal straight line while the raw coal curve, which showed an average of 30 per cent less heat absorption per pound of fuel, was curved downwardly. These curves showed that the heating efficiency and combustion of the smokeless fuel was uniform and was readily controlled like the burning of gaseous fuels, whereas the burning of the raw coal showed a lower efficiency, which was even less at the higher rates of burning.

The average Utah bituminous coal contains from 40 to 45 per cent volatile( ) matter by weight, that is, a piece of Utah coal is composed of approximately .4 gas and oil. When a piece of this coal is placed on a hot fuel bed in a heating appliance, these volatiles are driven off as the piece of coal reaches a dull red heat. In the modern power plant and heating boilers, provisions are made in the design so as to burn these gases and oil vapors as they are driven from the coal. In the house heating appliances, the combustion space is very small so that there is practically no possibility to design for smokeless combustion at all rates of burning. Consequently, as the coal heats up a large part of these gases and oils escape unburned into the chimney, and not only that, but they form a harmful black or yellowish sticky smoke. Therefore, most of the useful heat obtained from the coal is that which comes from the radiated and conducted heat of the red hot residue and the heat carried to the furnace walls by hot gases given off by the fixed carbon[(9)].

The data and the curves of the heating efficiencies of the raw and treated coal show that very little of the potential heat of the volatiles is "useful" heat. From this, one can see that if these oils and gases are extracted from the coal before it is burned, that this partly devolatilized smokeless fuel is merely the same as that product which is left in a fuel bed after the smoke has been driven from the raw coal. That is exactly what is done in this process of low-temperature carbonization.

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(9) See Appendix I.

The raw coal is placed in an air tight container and a heating medium (superheated steam) is passed around the coal lumps until they are heated to a temperature of from 800° to 1200° F. This drives off and extracts the oils and rich gases that would form smoke if they were liberated in a stove.

One now sees that the fixed carbon, ash,[10] and non-smoke producing volatiles are left in the treated coal. It will be noted further that the percentage of ash is higher in the remaining fuel. However, it has been determined that when this treated coal is burned in a heating appliance, it leaves practically no un-burned carbon in the ashes. Also it gives off more useful heat per unit of weight and, therefore, since the rate of burning is less per unit of time, the actual ash produced over a unit of time is approximately the same as that left from burning raw coal. Briefly, it may also be said, that the amount of ash formed per unit of useful heat obtained is the same as from raw coal.

In the many burning tests made with this new fuel in fireplaces, it was always noted by the authors and by the many visitors to the Fuels Laboratory, that the amount of radiant heat was vastly greater than from the burning of raw coal. The cheerful glow of the fire and the complete absence of soot always brought forth so many enthusiastic expressions from observers that the authors believe the psychological factor will be very important in overcoming the innertia in obtaining widespread public use of the new smokeless fuel.

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(10) See Appendix I

CALCULATION FOR A POWER AND COAL-TREATING PLANT

Based on a town of 1000 people

The complete designing and detailing for this plant would require several additional months time, so the following calculations are brief and preliminary. They will, however, serve to show the relative sizes of the different equipment required in such a plant and provide a picture of the entire installation.

CALCULATIONS:

The Uniflow engine is to run in series with the coal-treating retorts and operate against an assumed back pressure of 50 pounds absolute.

Number of Generating Units -125 K.W.	- - - -	2
Number of Boilers	- - - - - -	2
Steam Pressure,	Pounds per square inch	200
Superheat,	Degrees F.	200
Total Steam Temperature,	" "	584
Load Factor,	Per cent	35

Coal Analysis (Weber Coal - Coalville):

Proximate (from U.S.B.M. Tech. Paper 345)

Moisture,	Per	cent	13.7
Ash	"	"	4.4
Fixed Carbon,	"	"	43.6
Volatile Hydrocarbons	"	"	38.3

Heat Value, B.T.U. per pound 10,870

Boiler Sizes:

$$\frac{150 \text{ K.W. x assume } 25 \text{ lbs. per K.W.}}{34.5 \text{ lbs. steam per B.H.P.}}$$

$$= \frac{3,750 \text{ lbs. steam per hour}}{34.5 \text{ lbs. steam per hour per B.H.P.}}$$

$$= \qquad \text{B.H.P.} \quad 153$$

Use two 75 B.H.P. Boilers (Approximately 750 square feet each)

Run one boiler at 200% rating while maintaining second boiler as standby.

Type of Boilers:

Horizontal Return Tubular

Type of Stokers:

2 - Single Retort Underfeed Stokers to develop 187 B.H.P.

Superheater surface equal about 25% of Boiler Heating surface or

$$\frac{750}{4} = 187.5 \text{ square feet superheater surface.}$$

COAL RETORTS:

Assume 1 pound of steam is used per pound of coal treated. This is shown to be a logical figure from the discussion of results of the tests made with the 3 retorts in series.

3,750 lbs. of steam per hour

3,750 lbs. of coal per hour

Diameter of single retort equals 24" O.D. at bottom and 22" O.D. at the top.

Thickness of lids for top and bottom equals,

$$r \frac{w}{s}^{\frac{1}{2}} = 12 \frac{30}{5,000}^{\frac{1}{2}} = .93 \text{ (make 1")}$$

Where,

r = radius

w = load, - lbs. per sq. in.

s = allowable stress, - lbs. per sq. in.

Thickness of retort walls $= \frac{wr}{5,000}$

$= \frac{50 \times 12}{5,000} = .12$ in. use Gage No. 8 sheet iron.

Retort 23 inch average diameter will hold

$\frac{23}{11}^{2}$ x 300 lbs. for 11" average diameter, or

1300 lbs. of coal per retort for 23 in. average diameter.

Time required for each retort charge equals $2\frac{1}{2}$ hours for superheated steam and $2\frac{1}{2}$ hours for saturated or dry-quenching steam, or a total of 5 hours treating time allowing 1 hour for emptying and filling = 6 hours total.

Therefore, $\frac{24}{6} \times 1300 = 5200$ lbs. of coal per retort, per day.

$$\frac{3{,}750 \text{ lbs. steam per hour} \times 24 \text{ hours}}{5{,}200 \text{ lbs. coal per 24 hours}}$$

$=$ 17.3 retorts; use 18 retorts.

90,000 lbs. of coal per day equals 45 tons of raw coal treated per day, or an output of .6[11] x 45 = 27 tons of smokeless fuel per 24 hour day.

3,135[11.] cubic feet gas per ton x 45 = 141,000 cubic feet of gas per 24 hours at approximately 650 B.T.U. per cubic foot.

186 lbs. of crude oil per ton or 22.1[11.] gallons of crude oil per ton.

22.1 x 45 = 1000 gallons of crude oil per 24 hours.

This crude coal oil will produce by the ordinary petroleum refining methods: [11.]

250 gallons of gasoline,

250 gallons of diesel oil,

150 gallons of diesel oil, road oil, and tar acids,

2,500 pounds of ashless coke, and

20,000 cubic feet of 1300 B.T.U. Gas.

(11.) "Engineering Factors Relating to the Production of Smokeless Fuel, Oil and Gas From Rocky Mountain Coals by Low-Temperature Carbonization", by G. W. Carter, Master's Thesis in Mechanical Engineering, University of Utah, 1934.

COAL AND BINS:

Weight of coal per cubic foot - 40.25 lbs.[12]

Weight of coke per cubic foot - 37.40 lbs.[13]

Assume a 3-day storage of raw coal and a 14-day storage of coke.

Coal required for boilers:

Temperature of Water entering boiler -

200 lbs. per sq. in. pressure	-	354.9° F.
Heat of vaporization , B.T.U.	-	843.2
Mean specific Heat	-	.548
Heat to superheat = Ct' (2) - B.T.U.	-	109.6

(.548 x 200 = 109.6)

Total heat required from coal for 1 pound of superheated steam, B.T.U. - - - - - 952.8

(109.6 + 843.2 = 952.8 B.T.U.)

90,000 lbs. of steam per 24 hours x 952.8

= 85,800,000 B.T.U. per 24 hours.

So,

$$\frac{85,800,000 \text{ B.T.U. per 24 hours}}{10,870 \times 60\% \text{ efficiency}} = 13,180 \text{ lbs. of coal}$$

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(13) "Engineering Factors Relating to the Production of Smokeless Fuel, Oil and Gas From Rocky Mountain Coals by Low-Temperature Carbonization", by G. W. Carter, Master's Thesis in Mechanical Engineering, University of Utah, 1934.

(12) "Steam Power Plant Engineering", by Gebhardt, Sixth Edition, 1928.

per 24 hours = 6.59 tons per 24 hours.

Assume, therefore, that 7.0 tons of coal will be burned for boiler fuel.

RAW COAL STORAGE:

So, $(7 + 45)3 = 156$ tons storage capacity for raw coal. (3 days)

$$\frac{156 \times 2000}{40.25} = 7{,}750 \text{ cu. ft. storage}$$

Or,

$$\frac{7{,}750}{156} = 49.7 \text{ cu. ft. per ton}$$

(use 50 cu. ft. per ton)

The boiler fuel (-3/8" to dust) storage will be:

50×7 - cubic feet. = 350

The four larger sizes (+ 3/8" to 3") separated into equal volumes will be,

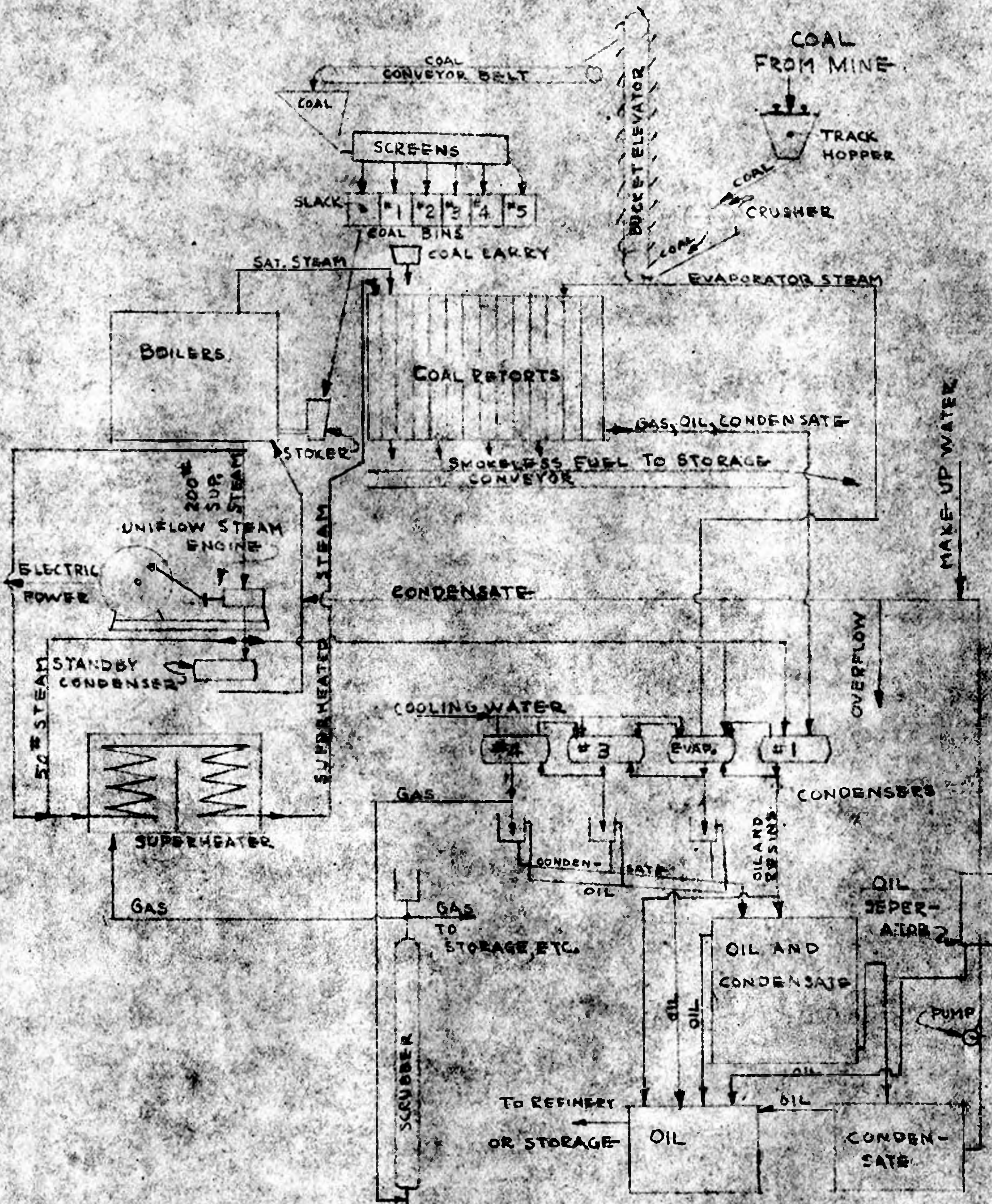
$$\frac{7{,}750 - 350}{4} = \text{cu. ft. per bin.} - 1{,}850$$

or a 5-compartment bin 25 feet wide x 21 feet long x 15 feet high.

SMOKELESS COAL STORAGE:

$$\frac{27 \times 14 \times 2000}{37.40} = \text{cu. ft. volume} \quad 20{,}200$$

or a battery of bins 25 wide x 40 feet long x 20 feet deep.



FLOW SHEET FOR
POWER PLANT IN CONJUNCTION
WITH COAL TREATING PLANT.

Estimate of Costs and Profits

For Installation and Operation of a 150 K.W. Power Plant

In Conjunction with a 45-Ton Low-Temperature Carbonization Plant.

From Gebhardt's, "Steam Power Plant Engineering", Sixth Edition, it is found that the cost per kilowatt for a 500 K.W. plant including spare boiler, auxiliary apparatus, etc., is $250.00.

Therefore, using $250.00 per kilowatt for this plant, and $500.00 per ton of daily treating capacity for the cost of the bins, retorts, superheater, conveying and screening system, condensers, and crude oil handling equipment, etc., for the coal processing, it is found that the approximate cost of the installation of such a plant would be,

150 x $250.00	=	$37,500
45 x $500.00	=	$22,500
Total Cost of Installation	=	$60,000

For depreciation annuity at 4 per cent and an average life of 13 years, it is found to equal 6 per cent of the first cost, or 60,000 x .06 = $3,600 per year.

COSTS: -

$$\frac{3,600}{45 \text{ tons raw coal} \times 365} = \$\ .219 \text{ per ton coal treated}$$

Interest at 6% on borrowed capital	= .219	"	"	"	"
Taxes and insurance at 3%	= .109	"	"	"	"

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Labor and Supervision:

7 men at \$1500.00 per year,

is $\frac{10,500}{45 \times 365}$ = \$ .640

Fuel and supplies =	.450
Coal for treatment =	1.250
Total per ton of coal treated =	\$ 2.882

Assume price of coal and products at plant:

Cost of raw coal per ton (delivered)	=	\$1.25
Price for treated coal (at plant)	=	4.50
Price for city gas at plant per M	=	.10
Price for crude oil at plant, per gal.	=	.05
Price for electric power at plant, per kilowatt hour	=	.01

RECEIPTS:-

		Per Day	Per Ton
Treated coal 27 x 4.50	=	\$121.50	\$2.70
140,000 cubic feet gas @ 10¢ per M	=	14.00	.31
1,000 Gallons crude oil @ 5¢ per Gal.	=	50.00	1.11
1,200 Kilowatt hours of electricity	=	12.00	.27
Total Receipts	=	\$197.00	\$ 4.39

Profit per ton, \$4.39 - 2.88 = \$1.51 or = 41.5% on investment.

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CONCLUSIONS

This year a low-temperature carbonization plant was built in the Coal Research Laboratory at the University of Utah, large enough to be classed as a pitot plant. From this plant sufficient data were taken to further varify previous research on the subject and to base the calculations for a large commercial plant. Enough by-products, smokeless fuel, curde oil, and gas were obtained to permit ample testing and use of them.

The tests made on the by-products were focused mainly on the smokeless fuel because of the very thorough studies that were already made by Mr. L. C. Karrick.

The conclusions made on the testing of this smokeless fuel vs raw coal are as follows:

1. The smokelsss fuel is positively smokeless, no matter how fired.

2. A fire can be started as easily with the smokeless fuel as with the raw coal in any of the common forms of domestic heating appliances.

3. The rate of combustion of smokeless fuel can be controlled more easily than the rate of combustion of raw coal.

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4. The efficiency of combustion of smokeless fuel is much higher and is much more constant over a wide range of firing rates than with raw coal.

5. The combustion of smokeless fuel is from 4.14 per cent more efficient in a cook stove to 65.9 per cent more efficient in a fireplace than raw coal.

6. Smokeless fuels made from most of the Utah coals leave no stain or dirty dust on one's hands after handling it.

7. This coal can be classified as an artificial anthracite coal, but with freer burning properties.

8. There is no need for anyone to purchase new house heating equipment in order to make Salt Lake City, or like towns troubled with excessive smoke, smokeless when this new fuel is placed on the market.

The conclusions reached regarding economic feasibility of the construction and operation of a commercial low-temperature carbonization plant for processing Utah coals, are as follows:

1. It is economically feasible to construct a low-temperature carbonization plant using the process tested in this thesis.

2. It is economically feasible to construct a low-temperature carbonization plant using this process in series with a steam-electric power plant and use the off-peak and exhaust steam for coal processing,

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while producing the power at a rate equivalent to the cost of maintaining the power-generating equipment.

3. The low-temperature carbonization of Utah coals will save a large economic loss of fuel, and of damage to property and health in our cities.

4. The establishment of a low-temperature carbonizing industry in Utah will expand the coal production from the Utah mines by supplying the heat energy consumed in the processing plants and by producing from Utah coal the oil products and the neeessary city and industrial fuel gas. The coal mines will then operate at a more uniform rate throughout the year, and be a great boon to labor and to the inhabitants in the coal mining areas of our state.

XVII

APPENDIX I

Definition and Description of Coal

Coal is a material which can be made to combine with other material in such a way as to liberate heat. Commercially, however, coal is thought of as a material, the greater part of which can be made to combine with oxygen from the air so as to liberate heat.

Composition of Coal:[14]

"(a) Coal consists principally of the elements, carbon, hydrogen, sulphur, oxygen, and nitrogen, together with moisture and ash. The elements named, particularly carbon, hydrogen, and oxygen, seem to be combined in various ways in the solid coal, though little is known of the formulas of the compounds in which they exist. The ash contains the inert salts of the original vegetable matter, together with silt and similar impurities acquired after deposition and submersion.

"(b) Moisture is arbitrarily defined as the material lost when a finely powdered sample of coal is maintained from half an hour, to an hours, at a temperature of about 220° F.; or, more exactly, as the maximum loss which can be made to occur at this temperature. The material driven off in this way is not necessarily all moisture, for, with some coals, part of the more volatile combustible material may distill off.

(14) Hirshfeld & Barnard, "Elements of Heat-Power Engineering", John Wiley & Sons, 1915.

Moreover, all the water content may be driven off by maintaining the material at this temperature. The definition is, therefore, only an arbitrary one, but it seems to be the best that can be devised.

"(c) Dry coal is coal from which the moisture has been driven off by heating, as above described.

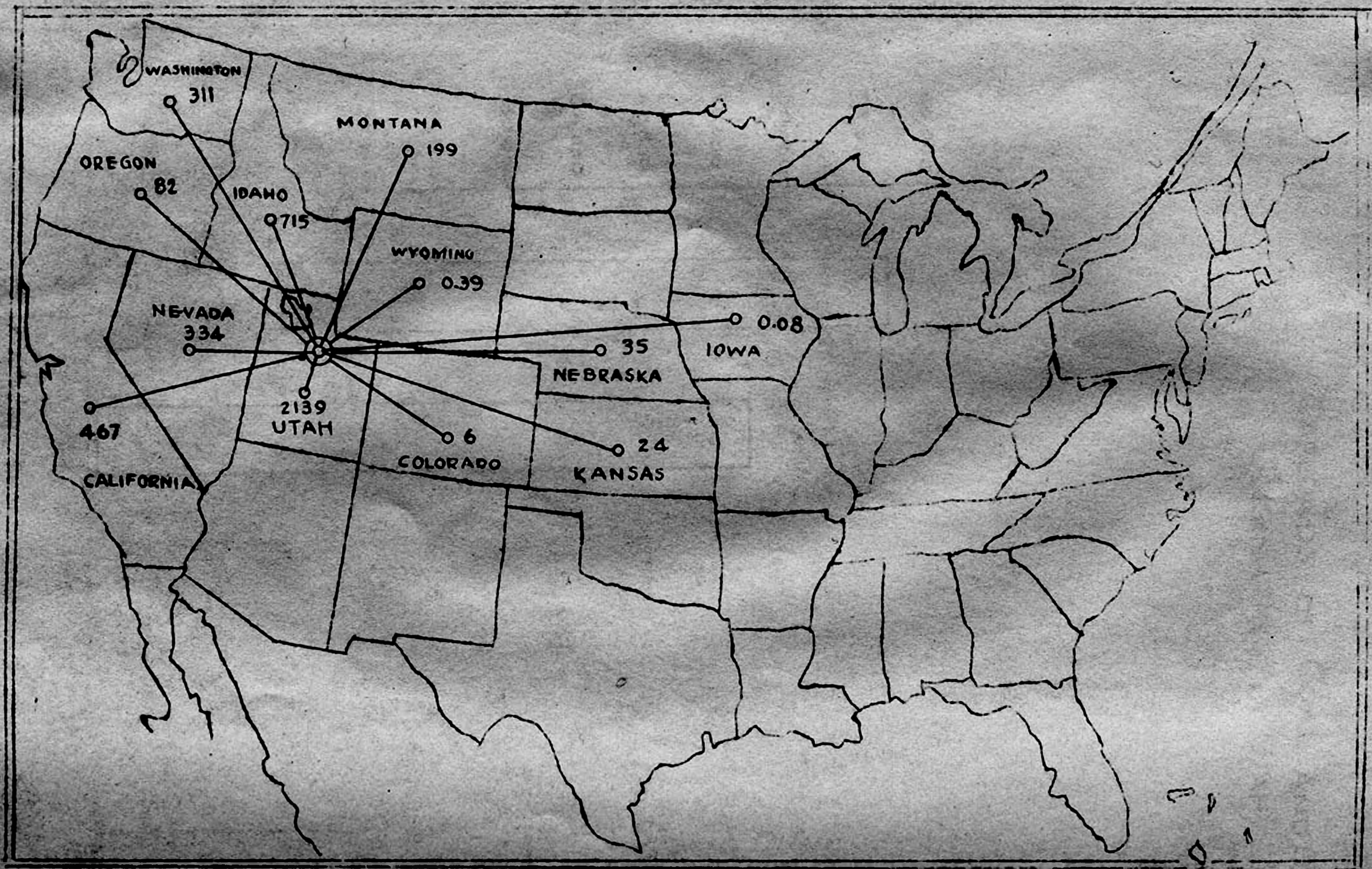
"(d) Volatile Matter (or "Volatile") is the name given to all material driven off when 'dry coal' is maintained at a very high temperature (between a 'red' and 'white heat') in a covered crucible (out of contact with the air) until there is no further loss of weight. This definition is purely an arbitrary one, but it is useful in that it gives a measure of the material which will be similarly given off in a furnace or in a coke oven.

"(e) Fixed Carbon is defined as the portion remaining after subtracting the ash from the material left in a crucible after driving off the volatile matter.

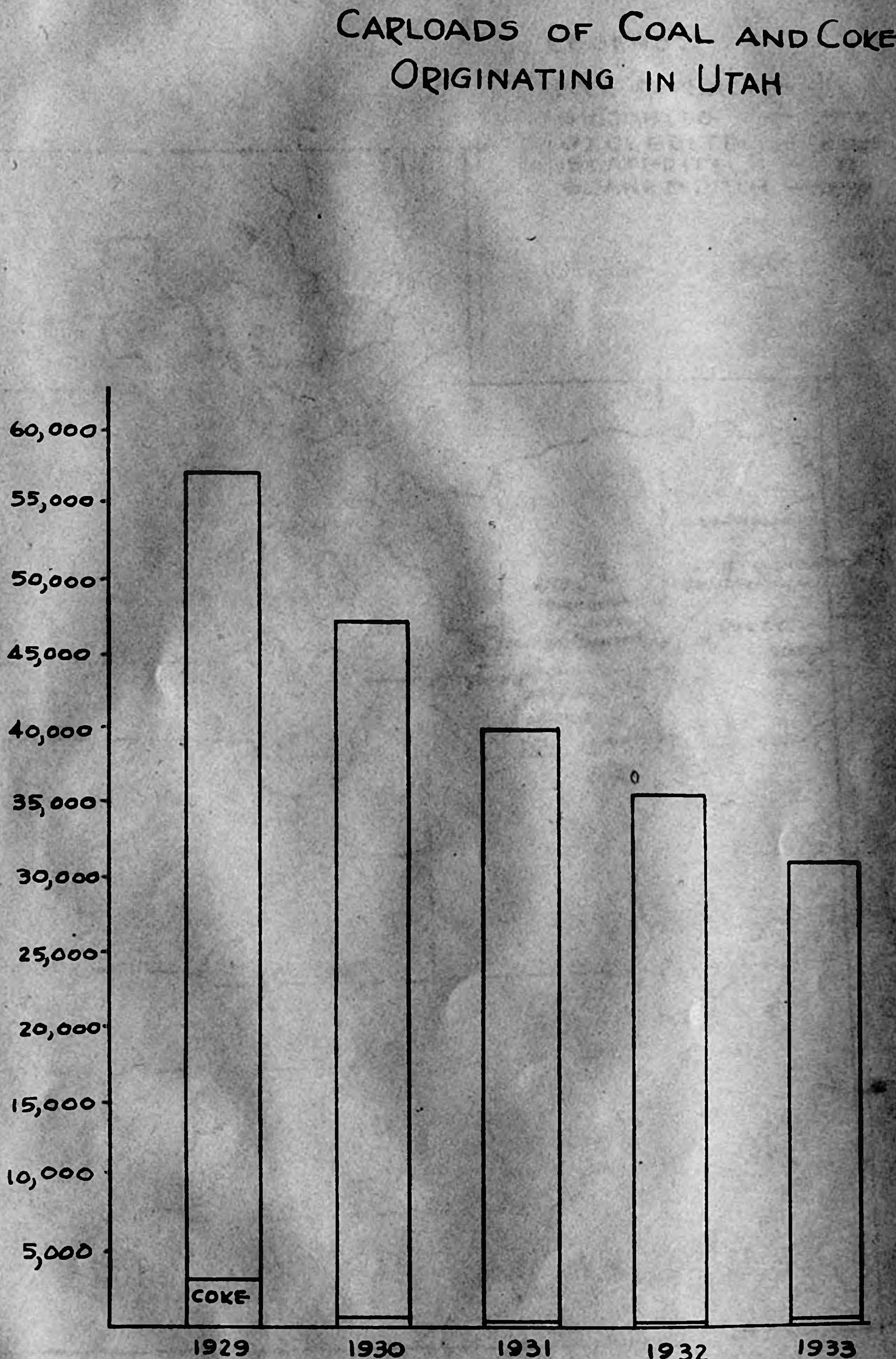
"(f) Combustible is the term used to designate the part of the coal other than moisture and ash. It is, therefore, the sum of fixed carbon and "volatile", as above defined. It is composed principally of carbon and hydro-carbons, but it is important to note that it also contains non-combustible matter such as nitrogen and oxygen, and hence, the term is a misnomer. When the coal contains sulphur a large part of this is also found in the so called combustible.

"(g) <u>Ash</u> may be defined as the material left after a sample of the finely ground coal has been burned completely for several hours with the aid of external heat such as a gas flame or electric heating coil."

APPENDIX II



DESTINATION OF UTAH COAL


CARLOADS OF COAL AND COKE ORIGINATING IN UTAH
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
COKE
1929
1930
1931
1932
1933

LOCATION OF HYDROCARBON DEPOSITS IN UTAH OTHER THAN IN COALS

BIBLIOGRAPHY

Brown, R. L., and Cooper, R. B.: "Composition of Light Oils From Low-Temperature Carbonization of Utah Coals", 1926.

Brown, R. L., and Branting, B. F.: "Composition of Tar From Low-Temperature Carbonization of Utah Coal..I", 1928.

Brown, R. L., and Pollock, R. N.: "Composition of Tar From Low-Temperature Carbonization of Utah Coal..II", 1929.

Carter, George W., and Jacobsen, S. Clark: "Engineering Factors Relating to the Utilization of the Cannel Coals of Southern Utah", Bachelor Thesis in Mechanical Engineering, University of Utah, 1933.

Carter, George W.: "Engineering Factors Relating to the Production of Smokeless Fuel, Oil and Gas From Rocky Mountain Coals by Low-Temperature Carbonization", Master's Thesis in Mechanical Engineering, University of Utah, 1934.

Davis, J. D., and Irey, K.M.: "Study of Wax from Low-Temperature Tar", 1934.

Frey and Yant: "Fractional Analysis of Gas From the Low-Temperature Carbonization of Utah Coal", Ind. Eng. Chem., 19, 21, 1927.

Gebhardt: "Steam Power-Plant Engineering", Sixth Edition, 1928.

Haslam and Russel: "Fuels and Their Combustion", Page 210, 1926.

Hirshfeld and Barnard: "Elements of Heat-Power Engineering", 1915.

Kinney, C. R., Burton, T.M., and Karrick, L.C.: "Cracking of Low-Temperature Utah Coal Tar", Salt Lake Mining Review, Vol. 35, No. 7, Page 5, 1933.

Schmutz, D. Clarence: "Oil Reserves in the Oil Shales and Coal Deposits of Utah, and the Economic Factors Affecting their Utilization", Master's Thesis in Economics, University of Utah, 1932.

Stutz, Clifford N, and Larsen, W. A.: "Design of Coal Treating Plant Using Karrick Process", B.S. Thesis in Civil Engineering, University of Utah, 1932.

XIII

"Smoke Abatement Handbook", National Smoke Abatement Society, 23, King Street, Manchester.

Taylor, John S.: "Smoke and Health".

U.S. Bureau of Mines Bulletin, No. 254, "Smoke Abatement Investigations at Salt Lake City, Utah."

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